Artificial Intelligence

Binary Classifiers for Multi-class Classification Problems

Pham Viet Cuong
Dept. Control Engineering & Automation, FEEE
Ho Chi Minh City University of Technology

Binary Classifiers for Multi-class Classification Problems

- ✓ Classification: A predictive modeling problem that involves assigning a class label to an example
- ✓ Binary classification: Classification tasks with two classes
- ✓ Multi-class classification: Classification tasks with more than two classes
- ✓ Binary classifiers:
  - ❖ Support Vector Machines
  - ❖ Perceptron
  - ❖ Logistic Regression

Binary Classifiers for Multi-class Classification Problems

- Multi-class classifications problems:
  - Handwritten digit (0, 1, . . ., 9)
  - Image classification ILSVRC2012
  - . . .

Binary Classifiers for Multi-class Classification Problems

- Binary classifiers for multi-class classifications problems:
  - One-vs-One
  - One-vs-Rest (One-vs-All)
  - Hierachical
  - Binary coding

Binary Classifiers for Multi-class Classification Problems

- One-vs-Rest:
  - Split a multi-class classification into one binary classification problem **per class**
  - A binary classifier is trained on each binary classification problem
  - Predictions are made using the most confident model
  - Example
    - Three class: sun, moon, star
    - Three binary classification problem
      - Binary Classification Problem 1: sun vs [moon, star]
      - Binary Classification Problem 2: moon vs [sun, star]
      - Binary Classification Problem 3: star vs [sun, moon]

Binary Classifiers for Multi-class Classification Problems

- ✓ Each model predicts a class membership probability (probability-like score)
- ✓ Class index with largest score (argmax) is used to predict a class
- ✓ Common used for Logistic Regression, Perceptron
- ✓ Cons:
  - ❖ Requires one model for each class (issue for large datasets, slow models, or very large numbers of classes)
  - ❖ Scale of confidence values may differ between binary classifiers
  - ❖ Unbalanced distributions between the sets of positives and negatives

Binary Classifiers for Multi-class Classification Problems

- One-vs-One:
  - Split a multi-class classification into one binary classification problem **per each pair of classes**
  - Fit a binary classifier on each binary classification problem
  - Example:
    - Three class: sun, moon, star
    - Three binary classification problem
      - Binary Classification Problem 1: sun vs moon
      - Binary Classification Problem 2: sun vs star
      - Binary Classification Problem 3: moon vs star

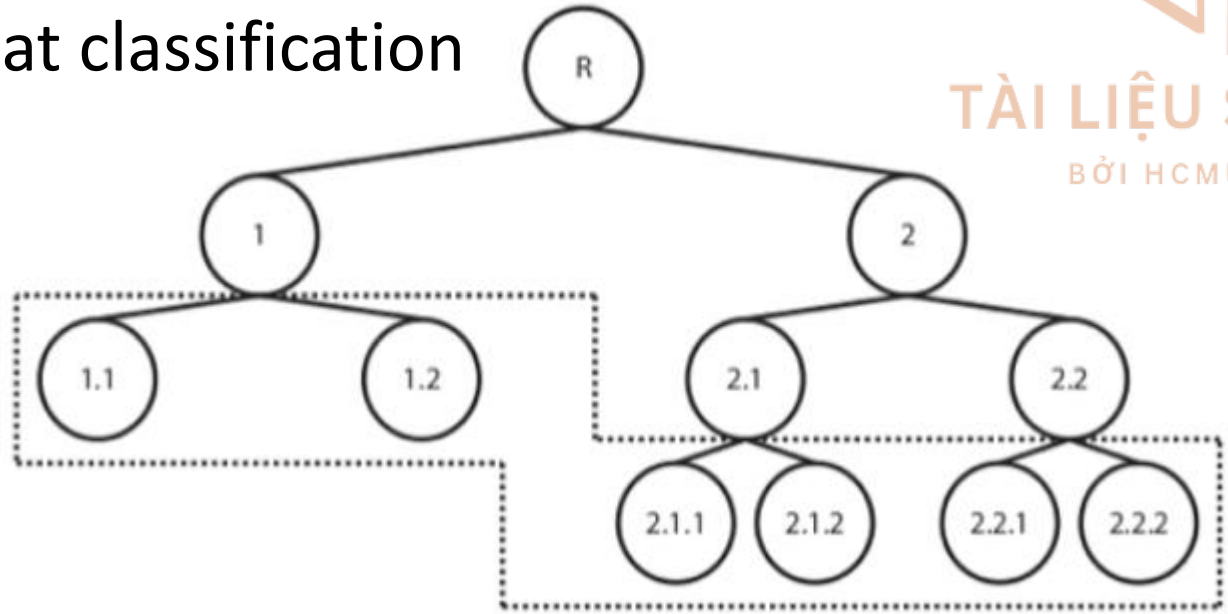
Binary Classifiers for Multi-class Classification Problems

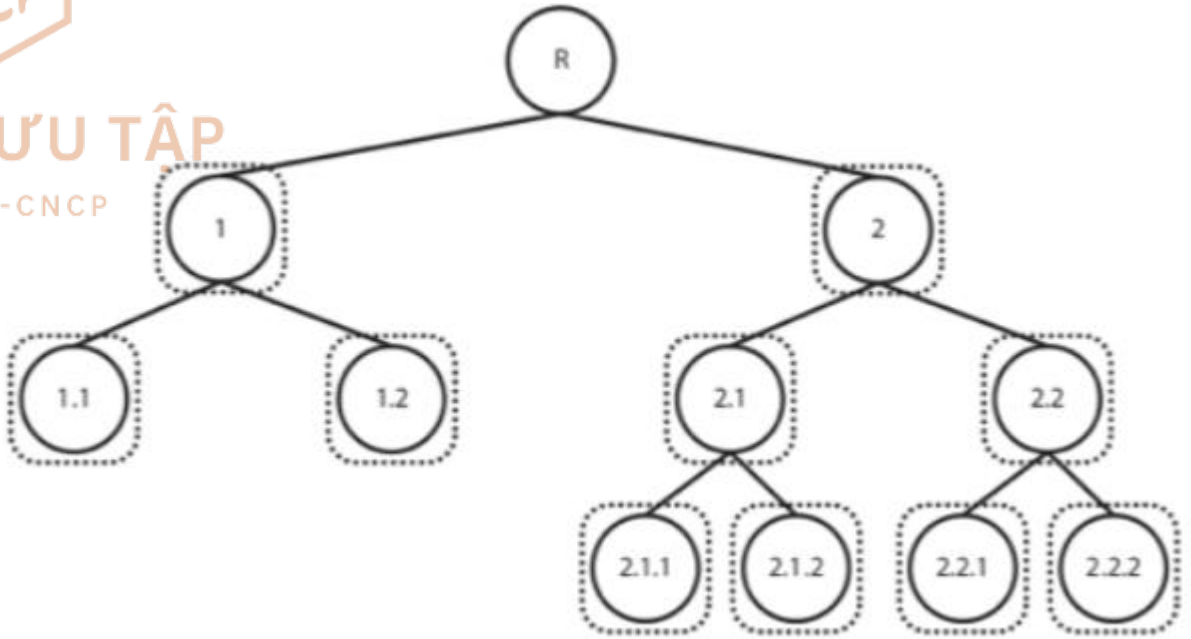
- ✓ Each data point: classified according to a majority vote
- ✓ If each model predicts a class membership probability: class index with largest sum score (argmax) is predicted the class label
- ✓ Cons:
  - ❖ Number of binary models: C*(C-1)/2, C: # classes
  - ❖ More models than the one-vs-rest
  - ❖ Requires one model for each pair of class (issue for large datasets, slow models, or very large numbers of classes)
  - ❖ Suffers from ambiguities (some regions of input space may receive the same number of votes)

Binary Classifiers for Multi-class Classification Problems

- ✓ Hierarchical classification:
  - ❖ Divide the output space i.e. into a tree
  - ❖ Each parent node is divided into multiple child nodes until each child node represents one class
  - ❖ Example

Flat classification



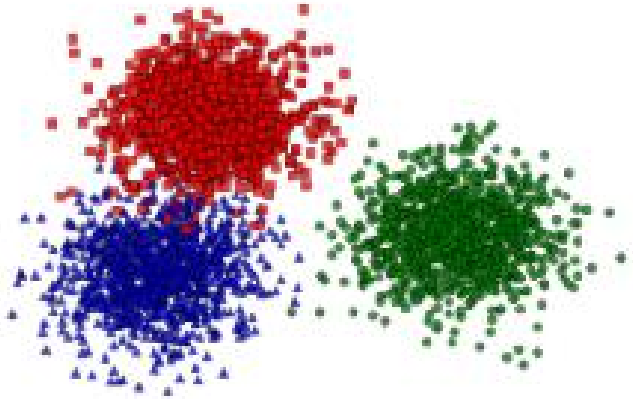


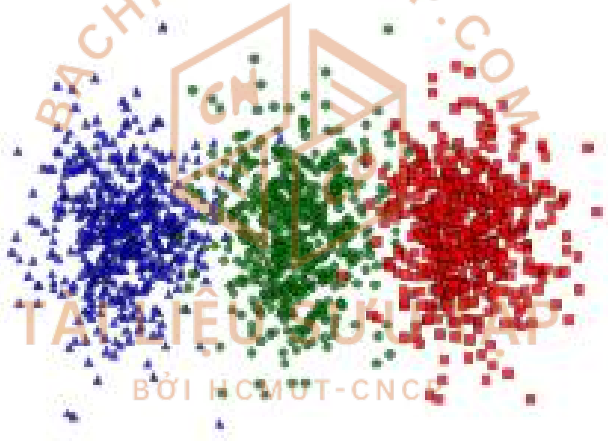
Binary Classifiers for Multi-class Classification Problems

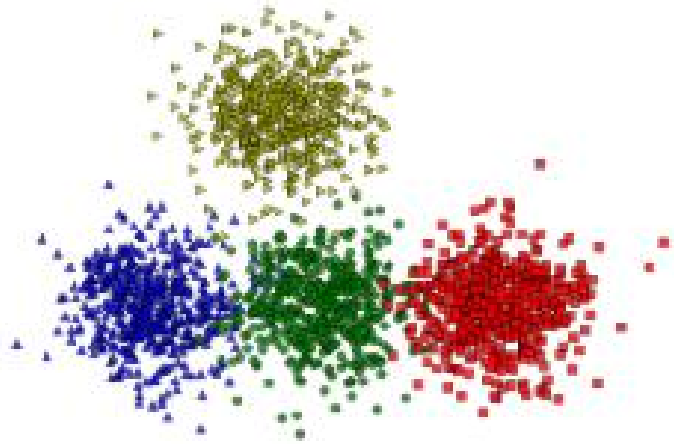
- Binary coding:
  - Encode class label by binary numbers
  - # binary classifiers = $\lceil \log_2(C) \rceil$ (C: # classes)
    $\lceil x \rceil$ = ceil(x): smallest integer greater than or equal to x
  - Least binary classifiers required
  - What if a bit incorrectly determinded?
  - What if # classes not a power of 2?

Binary Classifiers for Multi-class Classification Problems

- ✓ Linearly separable data:







Artificial Neural Networks

- References
  - https://machinelearningmastery.com/one-vs-rest-and-one-vs-one-for-multi-class-classification/
  - https://en.wikipedia.org/wiki/Artificial_neural_network